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Sentinel -1B Preliminary Results Obtained During the Orbit Acquisition Phase [Work in Progress]

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Abstract

This paper provides the status of the Sentinel-1B performance as at a few weeks after launch.

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Keywords: synthetic aperture radar (SAR); Sentinel-1B; radiometric calibration/validation

1. Introduction

Sentinel-1 (S-1) [1] is a constellation of two polar orbiting satellites. The first unit, S-1A, was launched on 3rd of April 2014 and the second unit, S-1B, on the 25th of April 2016 both from the European spaceport in Kourou by a Soyuz rocket. Both satellites are equipped with state-of-the-art C-band Synthetic Aperture Radar (C-SAR) instruments having electronic steering capability in elevation and azimuth allowing great flexibility in SAR data acquisition, in terms of resolution and coverage.

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S-1 being a constellation, the second satellite S-1B needed to acquire not only the same S-1A orbit but also a specific node. The two satellites are flying 180° apart in order to achieve 6-days revisit time span in interferometric conditions (i.e. half the time of S-1A alone).

The S-1B Launch and Early Orbit Phases (LEOP) phase ended on the 28th of April 2016 with no major issue encountered during the deployment and functional check-out. This phase was followed by the Orbit Acquisition Phase (OAP), whose purpose was to acquire the requested node in the orbit. The OAP was planned to be ended by mid-June 2016 when the actual instrument and product calibration phase will start. During the OAP, S-1B was drifting, impeding interferometric verification or activities requiring systematic acquisitions over calibration sites. During this period, the focus was instead placed on system characterization not dependent on orbital conditions.

Nevertheless some data was acquired allowing a preliminary analysis of the system calibration. This paper presents the S-1B preliminary results achieved as of 10 days before the end of the OAP. The results shown in this paper have therefore to be considered as not definitive.

2. Sentinel-1B first image

The first S-1B images were acquired at the end of LEOP on the 28th of April 2016 to perform a functional check of the C-SAR instrument. The data was acquired under the Svalbard station visibility downlinked and processed by the ground segment in record time [2].



Figure 1: S-1B first published image

The quality of the data acquired was already remarkable showing very limited radiometric artifacts. This was a very promising sign going in the direction of S-1A and S-1B being perfect twins.

3. Sentinel-1B instrument stability

The radiometric accuracy requirement is 1dB (3σ). Never before was such a strong requirement placed on a spaceborne system. In order to achieve it, it is mandatory to achieve a very stable instrument. The instrument stability is guaranteed by a dedicated internal calibration scheme [3]. The instrument stability was measured during the S-1B OAP using very long data-takes of 10 to 25 minutes. Figure 2 shows the internal calibration variation achieved from an IW data-take of 25 minutes showing a variation $<0.2\text{dB}$ in gain and $<15^\circ$ in phase. This variation is mainly due to the temperature increasing with time. The internal calibration being used by the ground processor removes these variations and so the residual variation is negligible. The S-1B stability is similar to what was achieved by S-1A

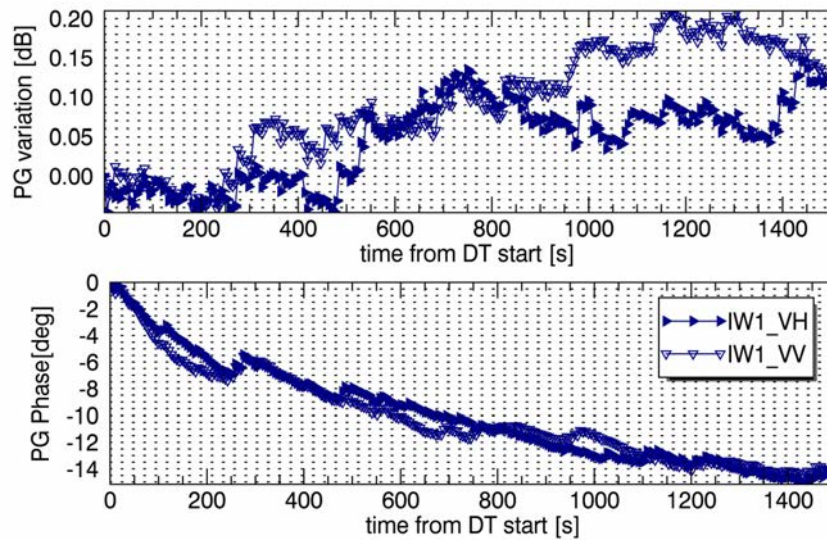


Figure 2: S-1B instrument stability over time in gain (top) and phase (bottom)

4. Sentinel-1B Doppler Centroid frequency stability

The S-1 platforms are steered in yaw and pitch in order to achieve the so-called *Total Zero Doppler Steering*. The azimuth pointing verification will be performed using azimuth notch (in transmit) recorded by the ESA and DLR transponders in combination with the Doppler Centroid Frequency (DCF) that is an excellent indicator of azimuth mis-pointing. Although a limited set of acquisition were being acquired at the time of writing it is possible to preliminarily assess the DCF performance. Figure 3 shows the DCF for all S-1B acquired so far. Not considering the first data-takes acquired at end of LEOP, it can be seen that the DCF stability is around 20Hz (1σ) with a bias of ~80Hz. The stability is similar to what is currently achieved by S-1A. For what concerns the bias, it will be reduced once the mis-pointing is characterized.

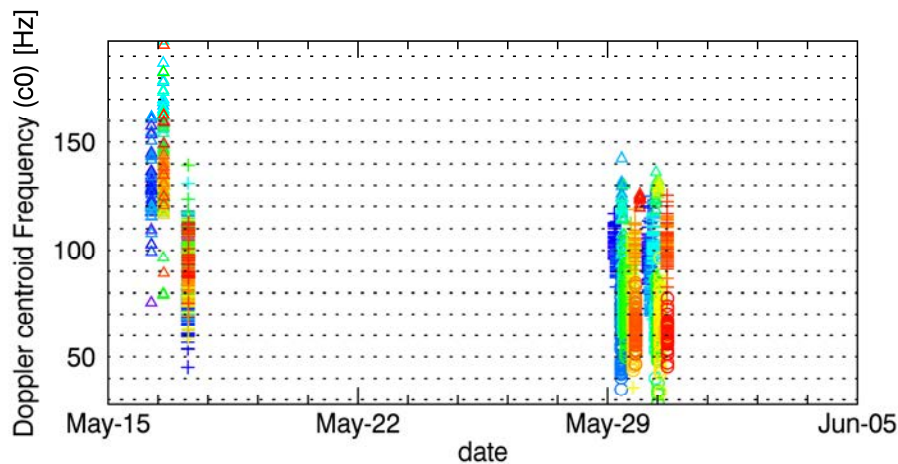


Figure 3: S-1B Doppler Centroid Frequency

5. Sentinel-1B preliminary noise equivalent sigma zero

Noise-Equivalent Sigma Zero (NESZ) is a measure of the sensitivity of the system to areas of low radar backscatter. It is given by the value of the backscatter coefficient corresponding to a signal-to-noise ratio of one. The NESZ is classically measured over water bodies under very low wind conditions. As S-1 is a dual-polarisation system, it is possible to use the cross-polarized channel, as it is less sensitive to wind conditions and thus reaches more quickly the instrument noise floor. Figure 4 shows the S-1B NESZ performance is very close to the expected values and compares already very well with S-1A. Given that the system is not yet radiometrically calibrated, it is premature to judge its final performance, but these results are another indicator showing that the instrument is behaving as expected.

It can also be seen that the S-1B NESZ measurements begin at slightly smaller off-boresight (i.e. elevation) angles than S-1A. This is an effect of the current orbit being higher than expected. Once the satellite is in the final orbital tube, the same range of angles will be experienced.

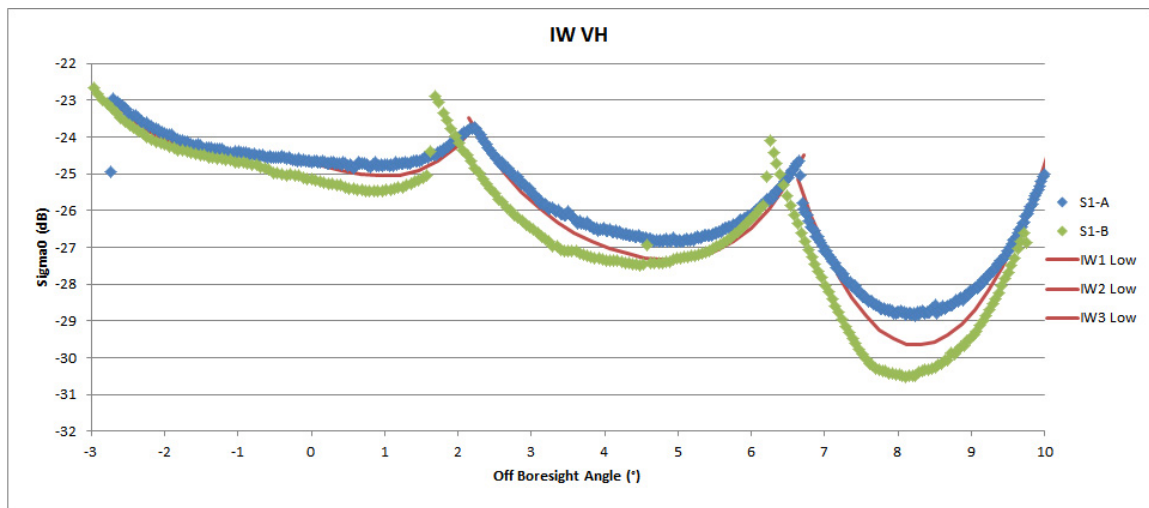


Figure 4: S-1B NESZ for IW in VH polarisation (green) comparing with S-1A IW VH (blue) and the expected profiles (red)

6. Sentinel-1B Preliminary geometric calibration

The geometric calibration of the S-1B will essentially be based on the Corner Reflectors (CR) deployed by University of Zurich and will follow the same approach as for S-1A [4]. On the 17th of May 2016 while still in the OAP, S-1B passed over the *Torny-le-Grand* site in Switzerland, imaging the CR deployed for descending passes. The Absolute Location Error (ALE) is defined as the difference between the *measured* and the *predicted* azimuth and range location of a given target. As defined in [4] the accuracy achieved is related to the quality of the orbit used and to the level of systematic corrections performed.

The S-1B data was processed using the GNSS orbit solution (provided by the on-board orbit determination system). Corrections for the atmosphere, tectonic frame shift and solid earth tide were applied offline. The ALE achieved with this single image was 8.70m in azimuth and 4.59m in range. Those results are not yet as accurate as that achieved with S-1A, but this was the very first image tested. The S-1A experience tells that this result is not dependent on the final orbit and thus can be trusted.

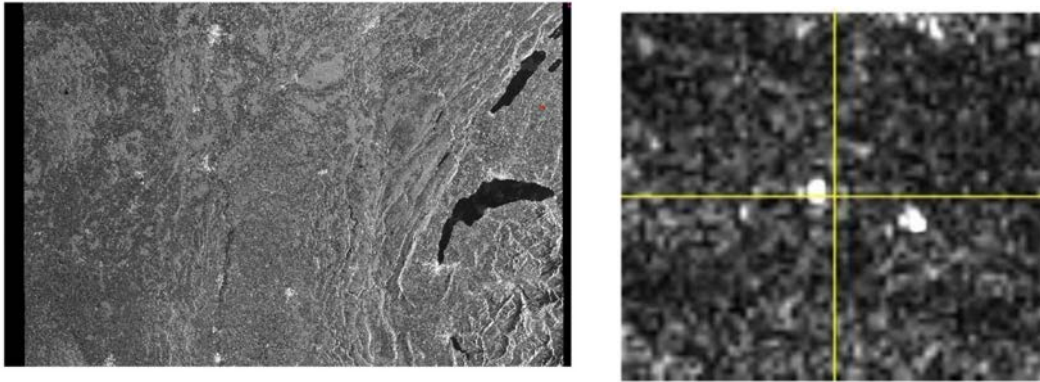
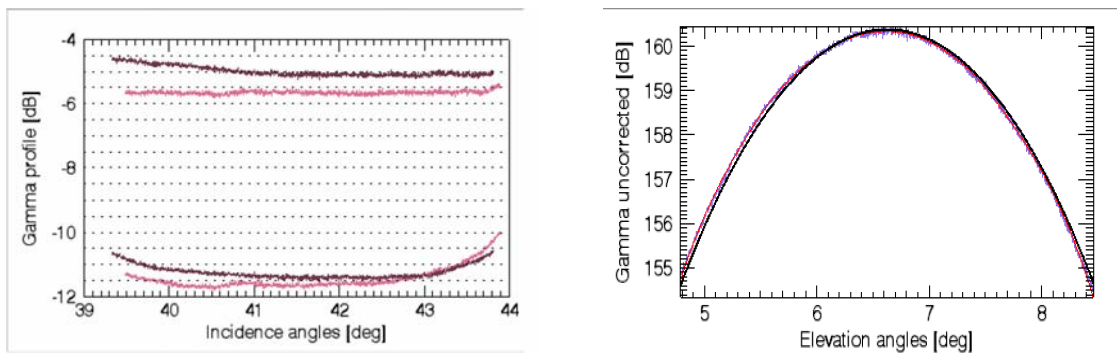


Figure 5: S-1B IW data acquired over the UZH Torny-le-Grand site in Switzerland acquired in IW1, descending pass (left). CR response with the cross-hair marking the predicted position (right)

7. Sentinel-1B preliminary elevation antenna pattern assessment

The second pillar of the S-1 calibration approach [3] is the S-1 Antenna Model (AM) [5] that is used in combination with the internal calibration to predict the Azimuth and Elevation Antenna Patterns (EAPs). For the EAP the AM verification will be performed over the Amazonian rainforest where the variations of the gamma profile can be statistically used to assess the EAP deviations. This approach has been used successfully for several C-band missions like ERS SAR, Envisat ASAR [6], RSAT-1 and 2. The difference is that for S-1 the rainforest is not used as mean to derive the EAP but as a verification of the AM prediction.

A first Stripmap product has been acquired over which it is possible to perform a first assessment of the antenna model prediction for S-1B. Figure 6.a) shows the S-1B gamma profile comparing with S-1A and b) the direct comparison with AM. Considering that the roll bias and the receiver gain variation haven't been characterized yet, the results achieved are showing a relatively good agreement. This will have to be confirmed with further results. As matter of fact the rainforest have diurnal and seasonal variation that requires the analysis to be performed with more data to be trusted statistically.



a) Gamma profile over the rainforest at HH and HV polarisation for S-1B S5 (darker color) and S-1A (lighter color)

b) Comparison between the S5 HH derived EAP (red) and the predicted pattern with the antenna model (black) pattern with the antenna model (black)

Figure 6: S-1B S5 HH EAP check-out

8. Sentinel-1B preliminary impulse response function assessment

Finally on the 29th of April 2016, the very first acquisition over the ESA transponders was successfully performed. The ESA transponders are mainly used for Impulse Response Verification (IRF) and radiometric calibration. From the IRF it is possible to derive basic quality parameters like the resolution and the sidelobe ratio characteristics. For this single measurement the resolution is very well within the requirement:: range 3.1 m, azimuth 21.8m. Side lobe ratio are also as expected.

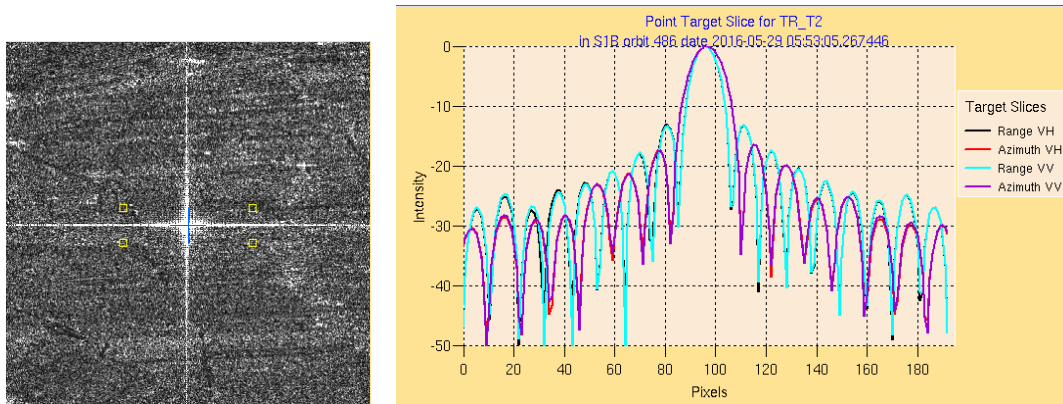


Figure 7: S-1B IW data acquired over the UZH *Torny-le-Grand* site acquired in IW1, descending pass (left). CR response with the cross-hair marking the predicted position (right)

9. Conclusions

At the time of writing, the S-1B spacecraft is still in the orbit acquisition phase. The satellite is being maneuvered in order to reach the required orbital node by mid-June 2016, when the intensive calibration activities will start. Although not yet in the final orbit, a first checkout of the instrument performance and calibration has been performed on a very limited data set. Although the evaluations to date are preliminary, all the results achieved so far seem to indicate that S-1B is a carbon copy of S-1A that will allow the efficient reuse of the experience from the S-1A routine operations during the S-1B commissioning phase.

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